Integrated Ground Operations Demonstration for Responsive Space Access

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Advanced Exploration Systems

- NASA's Advanced Exploration Systems (AES) program is pioneering new approaches to:
  - Rapidly develop prototype systems and subsystems
  - Mature and demonstrate key capabilities
  - Validate operational concepts for future human missions beyond Earth orbit
- Program goals will be achieved largely through of a set of vital and prioritized mission-capability-focused tasks
- Teams are comprised almost entirely of NASA civil servants (25 - 40 FTE)
- Limited procurement funding ($1M - $6M)
- Typically last 1 to 3 years to drive a rapid pace of progress
- 23 proposals selected across the Agency, including Integrated Ground Operations Demonstration Units (IGODU) project lead by KSC with participation from ARC, GRC and SSC

IGODU Background

- Cryogenic propellant loading operations and associated flight and ground systems are complex and critical to launch ops
- Sizeable portion of lifecycle costs of any launch program
  - Space Shuttle program's cost for cryogenic propellants at KSC and SSC was over $20 million/year between 2006-2009
  - 100+ propulsion/cryogenics experts monitoring propellant loading operations across the country on launch day
- NASA operations for handling cryogenics and our ground support equipment have not changed substantially in 50 years
  - Heritage Apollo era equipment

IGODU Background (cont'd)

- Integrated Ground Operations Demonstration Units (IGODU) project developed to mature, integrate and demonstrate advancements in cryogenics, system health management and command and control technologies

- Two Distinct Testing Environments:

GODU Integrated Refrigeration and Storage- GODU LH2

GODU Autonomous Control - GODU LO2

Project Scope and Goals

Scope

- **GODU LH2:**
  - Investigate alternative storage and distribution architecture for future cryogenic propellant operations
  - Demonstrate advanced cryogenic propellant handling operations (liquefaction, storage and distribution) of normal boiling point and sub-cooled cryogenic propellants
- **GODU LO2:**
  - Develop and demonstrate advanced control and health management technologies and techniques to autonomously control cryogenic propellant servicing operations
  - Investigate modern COTS hardware and control systems in an effort to reduce the "standing army" of engineers
- **GODU Helium:**
  - Develop and demonstrate helium conservation technologies

Goals

- Raise Technology Readiness Levels (TRL) and Integration Readiness Levels (IRL) of several key technology development areas
- Reduce operations lifecycle costs of future test programs and launch complexes
- Demonstrate technologies for future exploration beyond low earth orbit
- Serve as test environments for extraterrestrial surface operations

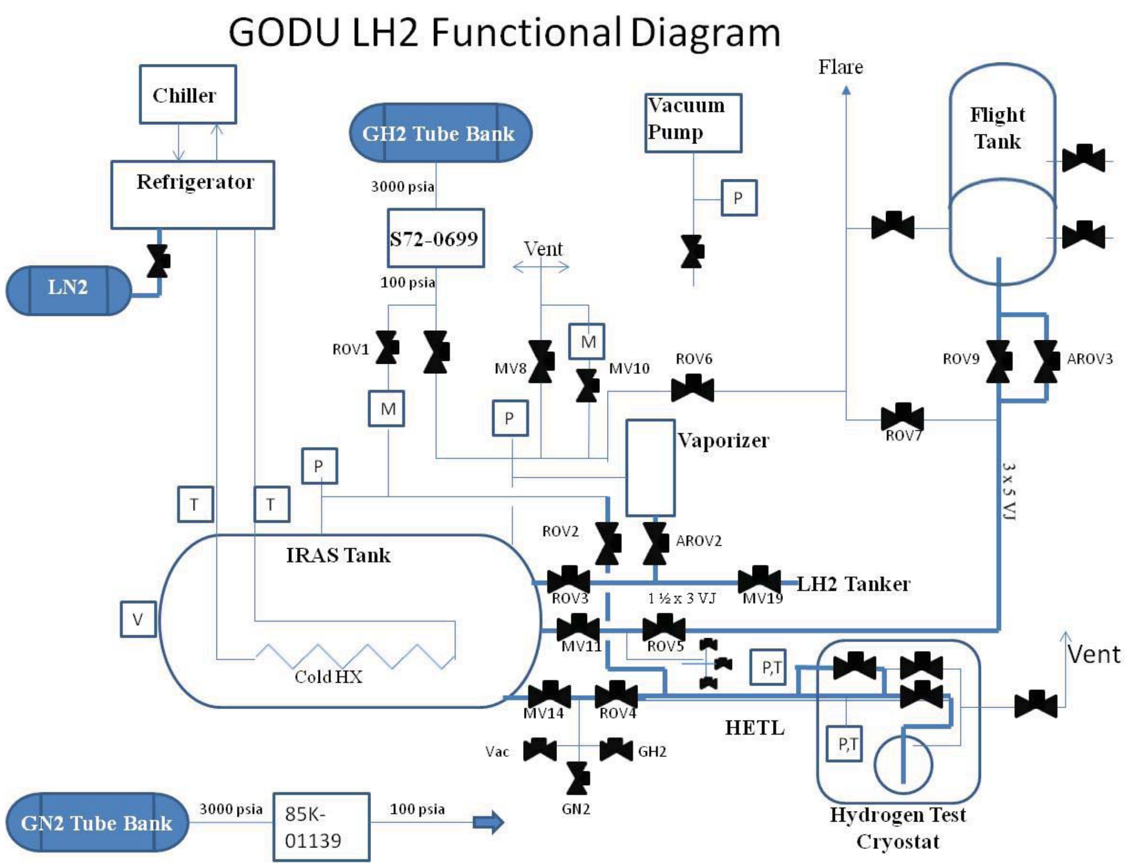
Need for Advanced LH2 Systems

- Kennedy Space Center (KSC) and Stennis Space Center (SSC) lose approximately 50% of hydrogen purchased
  - Continuous heat leak into storage and transportation vessels
  - Transient chilldown of warm cryogenic equipment
  - Liquid bleeds to maintain interface temperatures
  - Ullage losses during venting processes

Liquid Hydrogen Storage at KSC Launch Pad

Liquid Hydrogen in Use at SSC Test Stand

GODU LH2 Concept



- The key innovation of the GODU LH2 system is the integration of a cryogenic refrigerator into the LH2 storage tank.
- GODU LH2 will increase the IRL of an advanced LH2 system
  - No new component technology development
  - Industry standards in place of NASA GSE standards
- Reusing spare and excess equipment wherever possible

Integrated Refrigeration and Storage

- Commercial industry has made significant advancements in cryogenic refrigeration systems, specifically in Integrated Refrigeration and Storage (IRAS)
  - Large scale refrigeration systems in superconducting industry, but not for propellant storage
- IRAS concept allows liquid hydrogen to be stored in a quasi-equilibrium state
  - Cools liquid directly at storage site
    - Allows for control of the bulk temperature of the fluid as opposed to pressure control of the ullage using vent and relief valves
    - Enables easier depressurization of tank ullage pressure and bulk fluid conditioning for greater vehicle loading control
  - Operates with refrigeration capacity to system heat leak ratio greater than 1
- Concept has been proven at 180 liter scale using a COTS Gifford McMahon Cryocooler in partnership with the Florida Solar Energy Center
  - Evaluation of storage and handling characteristics of liquid hydrogen during in-situ liquefaction
  - Thermal stratification data collected during pressurization/depressurization cycles

GODU LH2 Objectives

- Primary Objective: Demonstrate efficient LH2 operations on a relevant scale that can be projected to future spaceport architectures by demonstrating the following:
  - Zero loss storage and transfer of LH2 at a relevant scale
  - Hydrogen densification in IRAS storage tank and loading of simulated flight tank
  - Hydrogen liquefaction using closed cycle helium refrigeration
- There are numerous secondary objectives, including:
  - Creation of a semi-portable densified LH2 servicing capability from excess equipment
  - Can be used at test stands, development centers, launch sites
  - Provide opportunity for retention of skills
  - Serve as a means of data generation for the Launch Services Program cryogenic tank thermodynamic model validation
  - Demonstrate modern component technology such as electric actuators, vapor shielded cryogenic piping, advanced instrumentation, and low helium consumption operations

GODU LH2 Work Status

- **GODU LH2**
  - All major procurements complete and hardware on site
  - Complete assembly, initial checkout with LN2 and LH2 zero loss transfer this fall
  - Detailed LH2 test series and system characterization in FY15
    - Liquefaction at three tank levels
    - Zero loss storage at three tank levels
    - Zero loss transfer from tanker
    - Densification and storage of densified propellant

Need for Autonomous Control Loading and Health Monitoring Systems

- Cryogenic propellant loading operations for the Shuttle program typically involved several large pockets of specialized engineers and managers from across the country (KSC, JSC, MSFC, Michoud and Rocketdyne).
  - Monitor propellant ground and flight systems during the critical final hours prior to launch.
  - Hazardous nature, complexity, criticality, and vulnerability of the launch vehicle and associated ground servicing systems
  - Lack of insight into system health

STS-135 Pre-Loading Simulation Team at KSC

Overview of GODU LO2

- The GODU Autonomous Control system resides at the Cryogenic Test Laboratory (CTL) at KSC and consists of
  - Small-scale Simulated Propellant Loading System (SPLS)
    - LN2 system simulating LO2 system
    - Propellant storage tank (6kgal)
    - Pumping complex (0-400 gpm)
    - Control valve skids
    - Vehicle simulator tank (2 kgal)
- Testing environment for advanced cryogenic components, sensors, and health management technologies.
- Demonstration of a control system capable of recognizing and automatically correcting simple system failures typical of heritage launch vehicle servicing systems.
  - Instrumentation failures
  - Thermal anomalies
  - Component failures
- Allows comparison, down select and maturation of the best ground health management and autonomous control concepts from ARC, SSC and KSC on typical cryogenic propellant servicing hardware.

Simulated Propellant Loading System (SPLS) at the KSC Cryogenics test Laboratory

GODU LO2 Objectives

- Demonstrate autonomous control of a sub-scale vehicle loading operation
  - Demonstrate recognition of common system faults and anomalies and recover without human intervention
  - Demonstrate small launch team control systems/concept of operations
- Evaluate tools and techniques in real world application to advance health management and autonomous control technologies for future applications
- Demonstrate scalability and extensibility by replicating autonomous control of the 6,000 gallon LO2 simulator system to a larger system
  - Ground Systems Development Office's Multi-User Spaceport Universal Propellant Servicing System (UPSS)
    - LO2/LCH4 propellant servicing systems for small class launch vehicles

GODU LO2 Work Status

- Automated testing series of pump fed system completed in May
- Autonomous testing series on going (June – Sept ‘14)
  - Two control systems under test
    - One knowledge based (NASA developed) and one rule based (commercial product – G2)
    - More details in Dr. Figueroa’s presentation on the G2 control system undergoing development and testing at KSC
- Conversion to LOX and LCH4 UPSS systems (FY15)
  - 30,000 gallon portable delivery systems
  - 400 gpm, pressure fed systems
- Multi-stage vehicle loading operations with LN2 (FY15)
- Multi-stage vehicle loading operations with propellants (FY16)

GODU Helium

- Overview
  - Helium is a non-renewable resource
  - Aerospace one of the world's largest consumers of helium gas
    - Only gas that's not condensable at liquid hydrogen temperatures
- Objectives
  - Develop and demonstrate technologies that can be used to reduce future helium consumption
    - Reduce, recover/reuse, or eliminate

GODU Helium

- Work Status
  - GRC/Makel sensor developed and tested in FY13 that enables real time monitoring of hydrogen system purge operations with solid state sensors
    - Prevents over purging and helium gas waste
    - SLS GSDO program funding qualification of these sensors in FY15 for use at LC 39B
  - STTR Phase III contract in FY13 demonstrated recovery of helium from He/H2 mixture
    - Sierra Lobo Inc. and University of Hawaii collaboration
    - Demonstrated at Stennis Space Center in September '13
  - No work planned in FY14 due to budget limitations

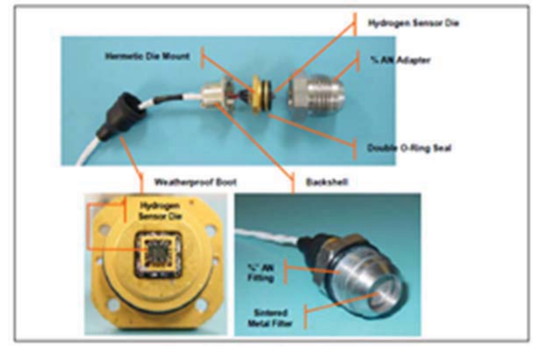


Figure 1 Hydrogen Sensor Assembly